ORBUMP Power Supply Design Review

Cezary Jach

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P.S. Load Physical Description

- Three (3) magnets in series – parallel configuration
- Single magnet inductance = 1.8 μH (measured)
- Single magnet dc resistance = 34 μΩ (calculated)
- Total load inductance = 2.7 μH
- Total load resistance = 51 μΩ
- Short stripline with maximum inductance of 40 nH
- Total of twenty (20) RG 220 cables in parallel, 75 ft long maximum

P.S. Current Requirements

- Nominal pulse amplitude = 15 kA
- Maximum pulse amplitude = 17.5 kA
- Maximum flat top duration = 50 μsec.
- Pulse flatness = ±0.5%
- Rise time
  - Minimum = 30 μsec.
  - Maximum = 40 μsec.
- Fall time
  - Minimum = 30 μsec.
  - Maximum = 40 μsec.

P.S. Current Requirements, cont.

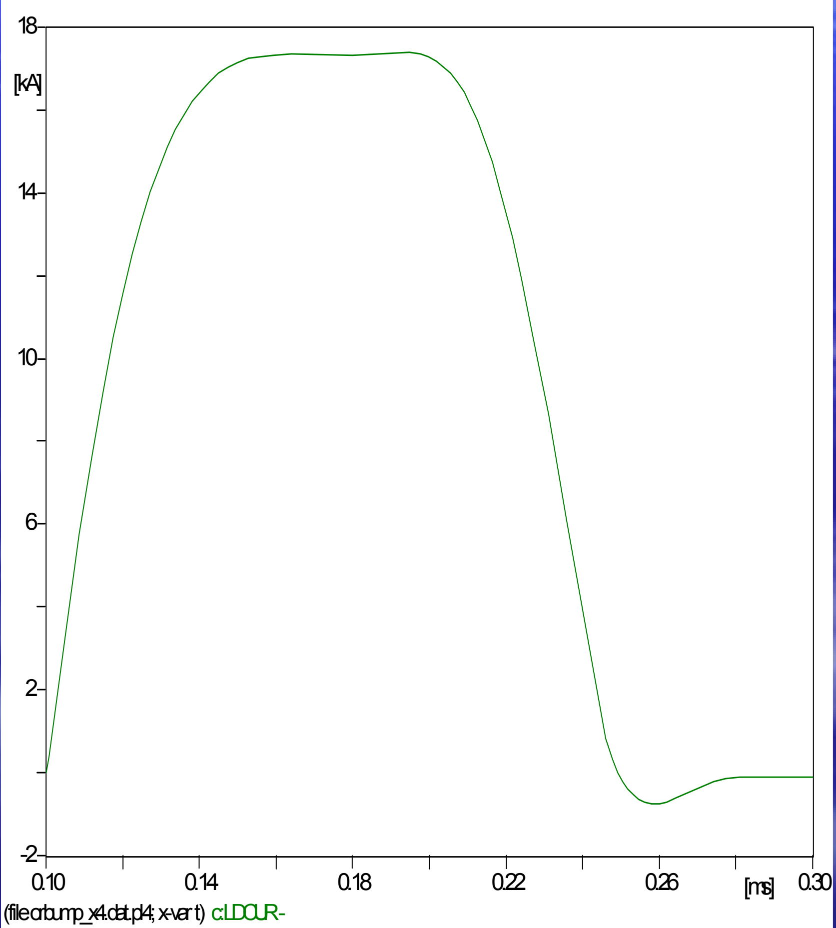
- Nominal repetition rate = 15 Hz
- Pulse repeatability = ±1%
- Undershoot
  - Maximum amplitude = 5%
  - Minimum duration = 10 μsec.

Power Supply Design Criteria

- Use Ken's new SCR switch
- Utilize as many MP01/MP02 elements as possible
- Utilize existing PFN inductors
- Fit existing ORBUMP power supply space and utilities
- Use line harmonic reduction equipment

Power Supply Current

- Pulse amplitude = 17.5 kA
- I_{rms} = 672 A
- Rise time (10% - 90%) = 33 µs
- Fall time (90% - 10%) = 36 µs
- Flatness = ±0.27%
- Pulse width = 50 µs



Switch Assembly

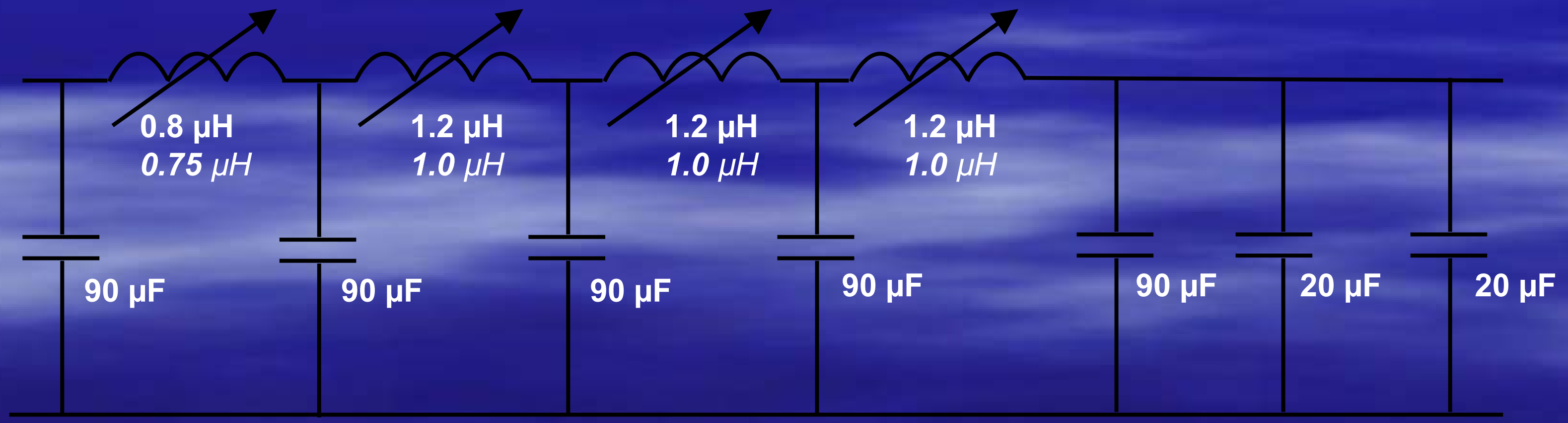
- 5 parallel switches
- 3 SCRs in series each
- CT monitoring total current
- Switch is assembled and tested
- 5 spare individual switches assembled and tested

Charging Power Supplies

- Four MP01/MP02 style charging power supplies needed
- Each supply is rated 3 kV, 6 A
- Need 2.05 kV, 3.35 A each

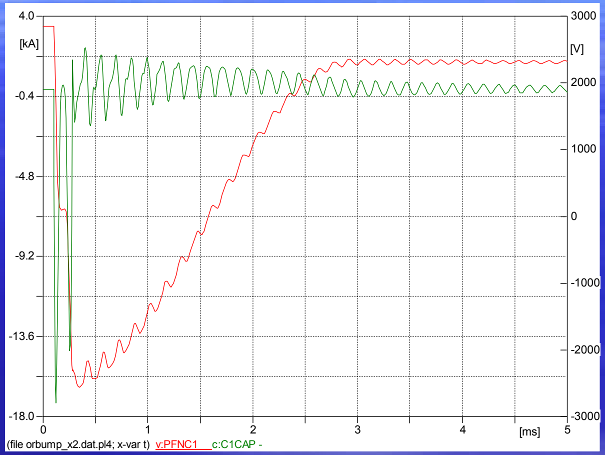
PFN

- 8% coupling between adjacent inductors (diagram below)
- 0% coupling simulated gave same results (inductor self inductance in *italic*)
- Additional capacitors to improve rise time
- Coupling measurements planned

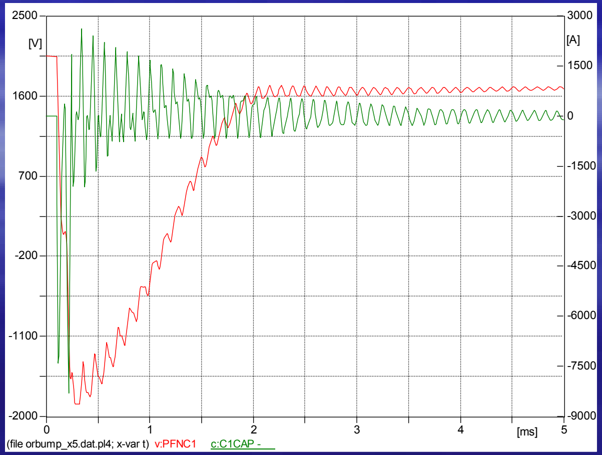


PFN Capacitors

- Available:
  - Capacitance = 180 μF (2 x 90 μF)
  - Voltage = ± 2.85 kV
  - Discharge Current
    - Peak = 17.2 kA
    - Rms = 500 A

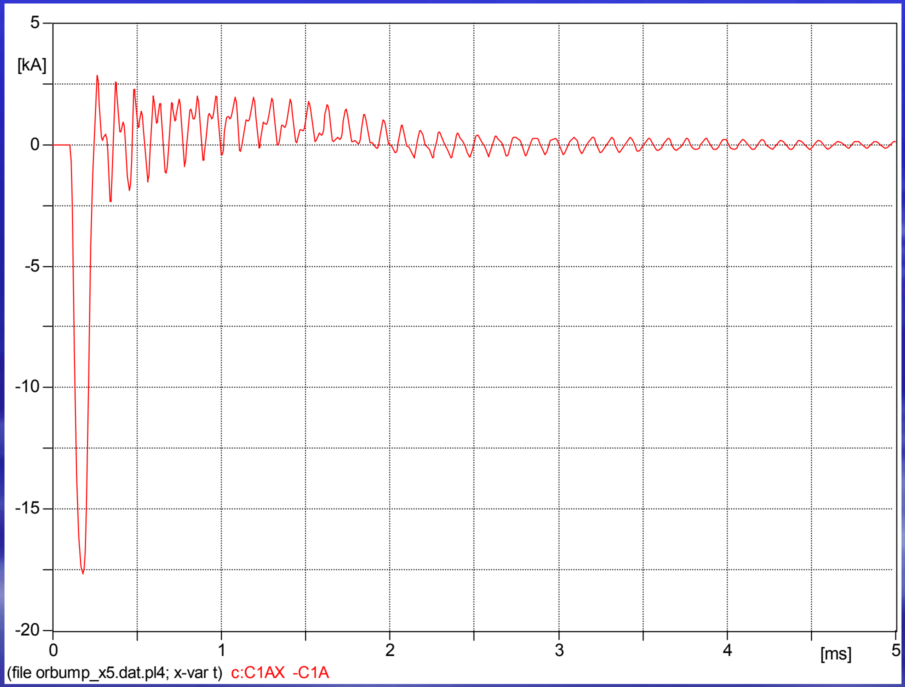


- EMTP Simulations:
  - Capacitance = 90 μF
  - Voltage = ± 1.86 kV
  - Discharge Current
    - Peak = 8.3 kA
    - Rms = 250 A



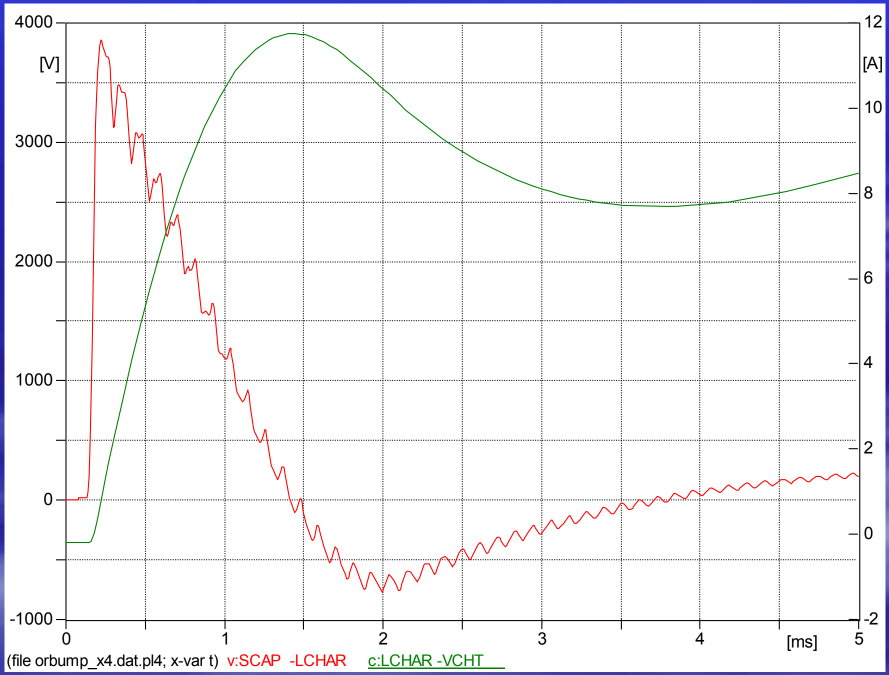
PFN Inductors

- Simulations:
  - L = 0.8 – 1.2 μH
  - Current
    - Peak = 17.7 kA
    - Rms = 575 A
- Existing Inductors:
  - L = 0.1 – 4.0 μH
  - Q = 1 – 6 (1 kHz)
  - Conductor size = 420 MCM
  - Water flow = 1.5 GPM
  - Current
    - Peak = 40 kA
    - Rms = 1.37 kA



Charging Choke

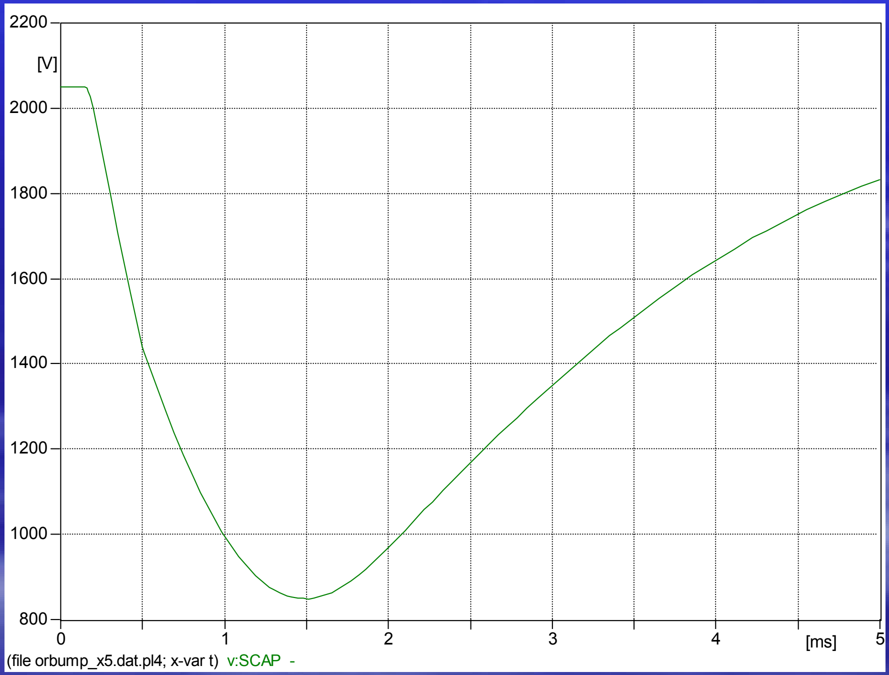
- Simulations:
  - L = 0.2 H
  - V = 3.85 kV
  - Charging Current
    - Peak = 13 A
    - Rms = 10 A
- MP01/MP02 choke:
  - L = 0.2 H
  - V = 5 kV
  - Charging Current
    - Peak = 80 A
    - Rms = 20 A



Charging Capacitor

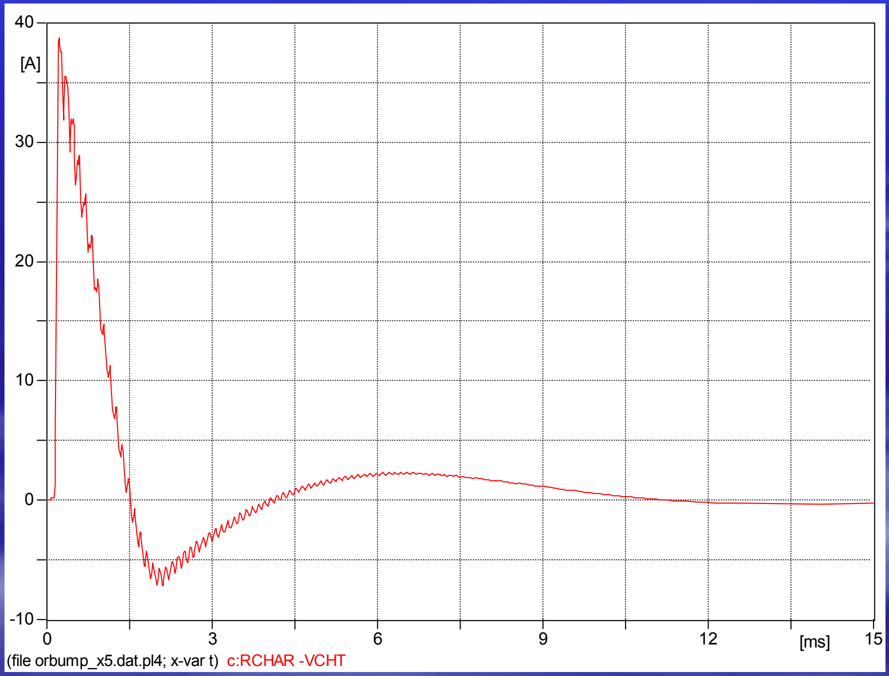
- Available:
  - C = 20 μF
  - V = 2,85 kV
  - Current
    - Peak = 1 kA
    - Rms = 20 A

- Simulations:
  - C = 20 μF
  - V = 2.05 kV
  - Current
    - Peak = 11.7 A
    - Rms = 7 A



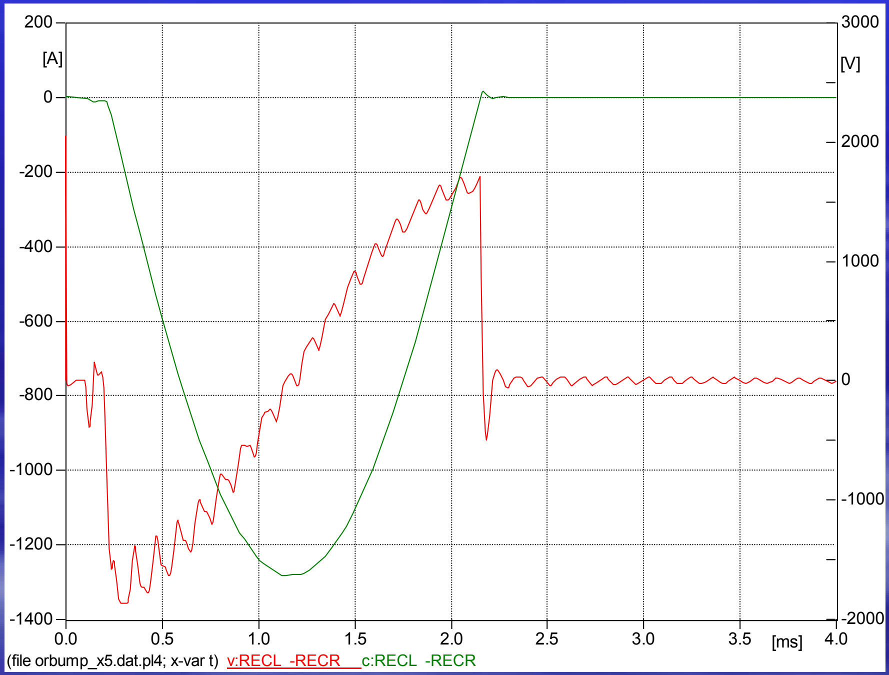
Charging Resistor

- Simulations:
  - R = 100 Ω
  - V = 3.85 kV
  - I_{rms} = 1.6 A
  - P = 256 W
- Available:
  - R = 100 Ω
  - V = 8.9 kV
  - I_{rms} = 3.2 A
  - P = 1000 W



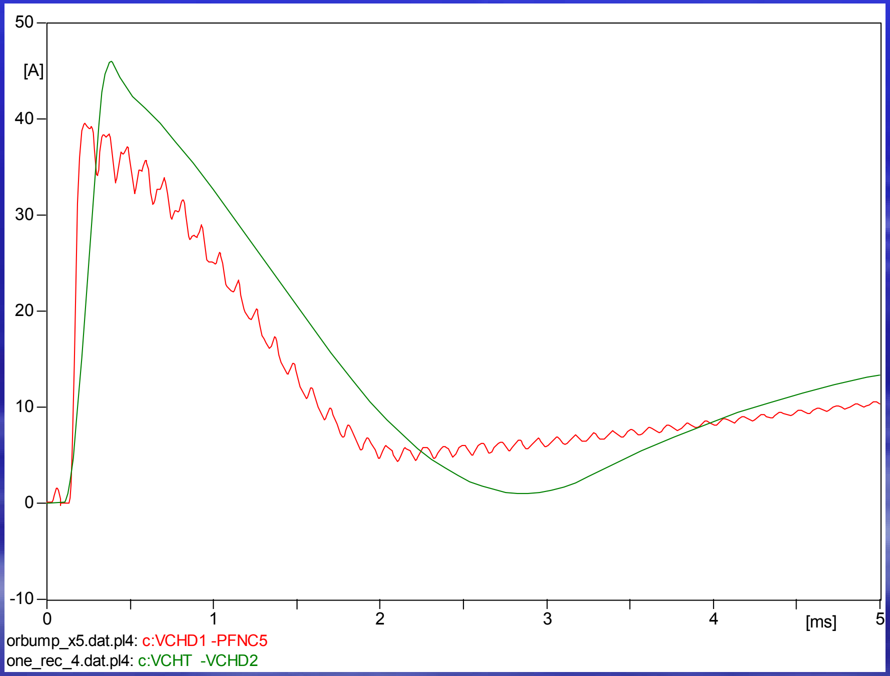
Charge Recovery Choke

- Simulations:
  - L = 0.8 mH
  - V = 1.8 kV
  - Current
    - Peak = 1.3 kA
    - Rms = 155 A
- MP01/MP02 choke:
  - L = 0.8 mH
  - V = 2.2 kV
  - Current
    - Peak = 2.5 kA
    - Rms = 400 A



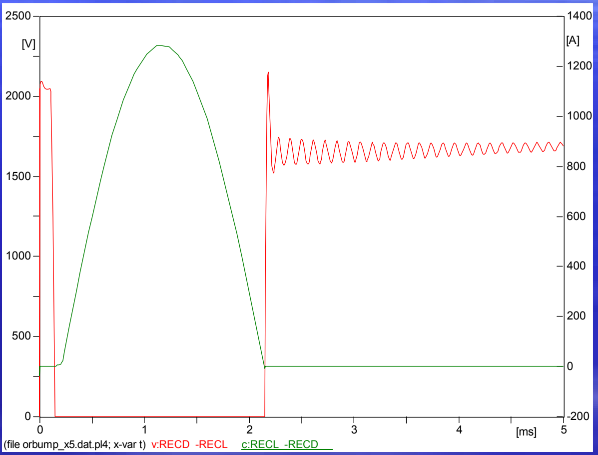
Charging Diodes

- Same as MP01/MP02 diodes
- Lower I_{max}, I_{rms}, V_{max}
- Same assembly as for charge recovery diodes

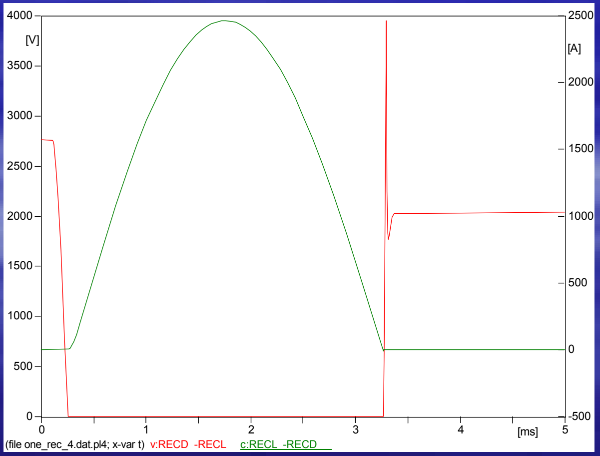


Charge Recovery Diodes

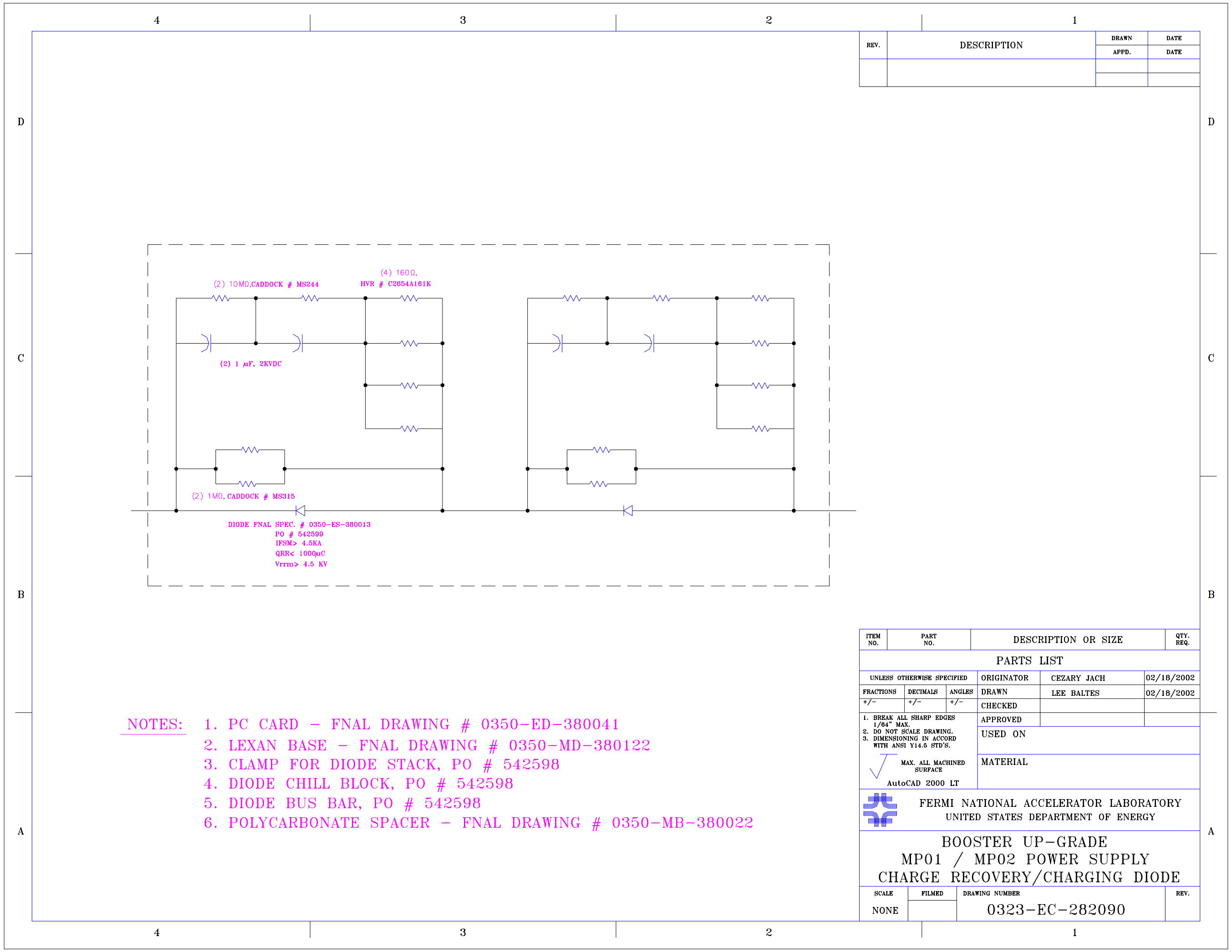
- ORBUMP Charge recovery diode



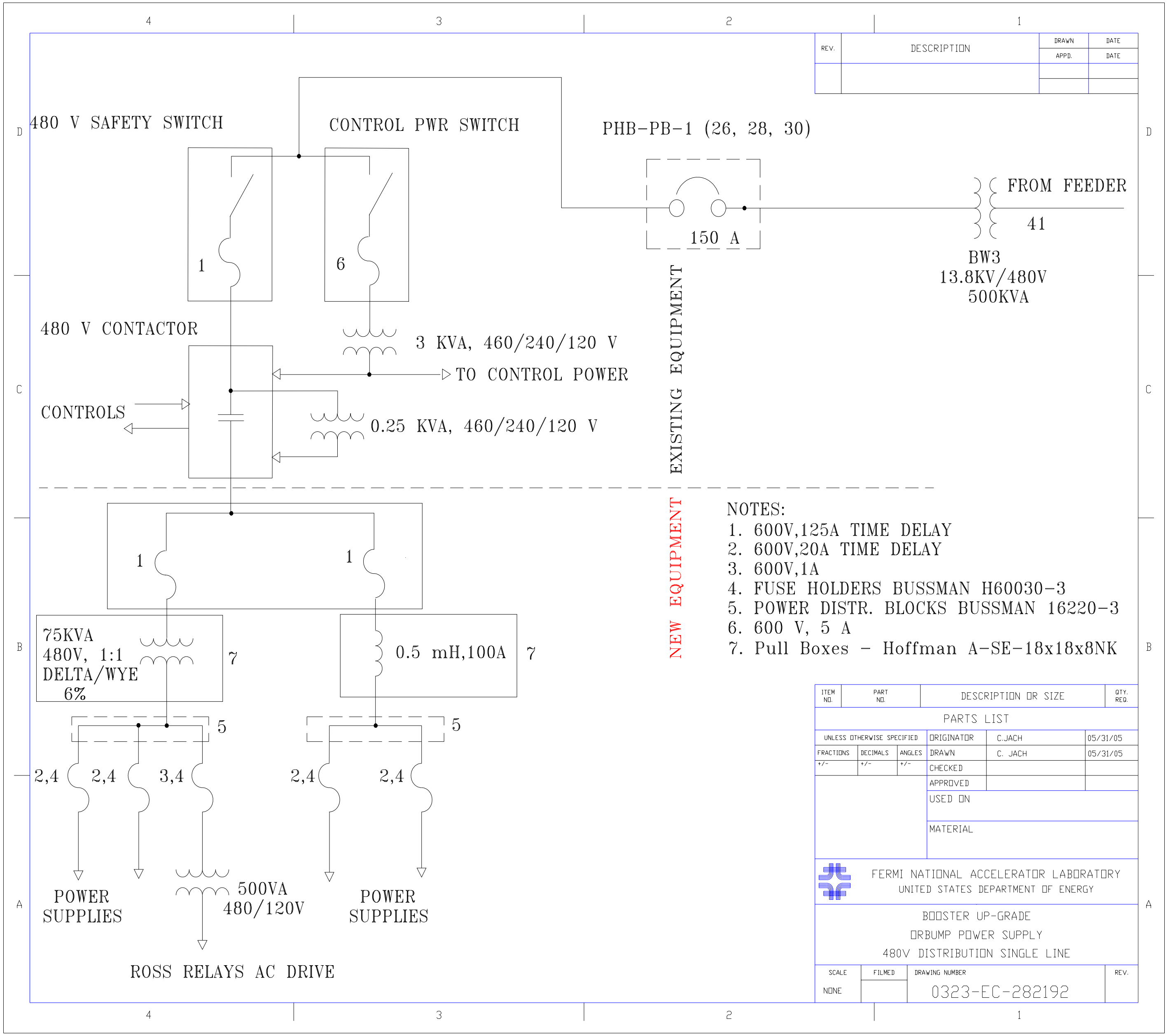
- MP01/MP02 Charge recovery diodes



Charging/Charge Recovery Diodes

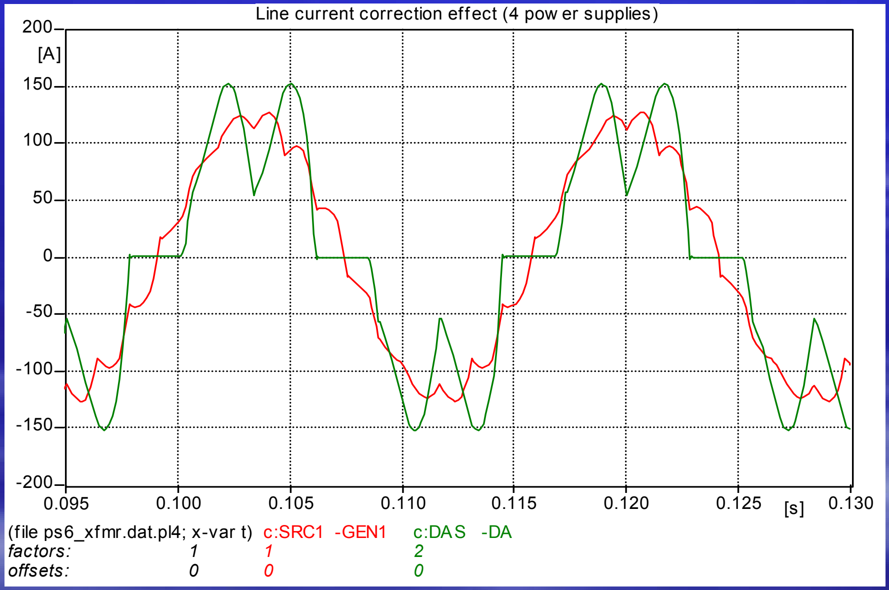


480 V Equipment



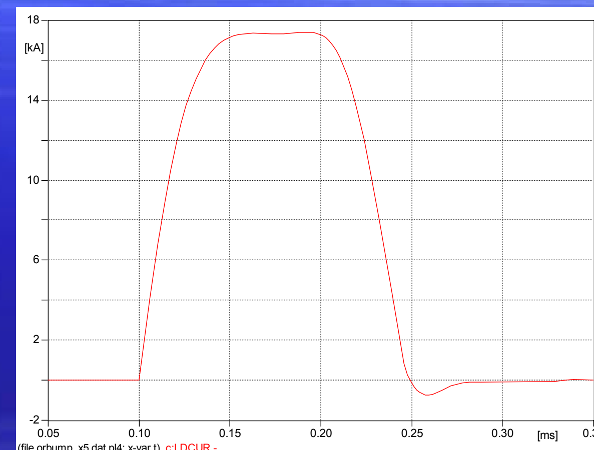
Line Harmonic Reduction

- Same system as for MP01 and MP02
- Effectively reduces current THD from 40% to 8%
- At 500 kVA transformer secondary voltage THD reduced from 19% to 1%

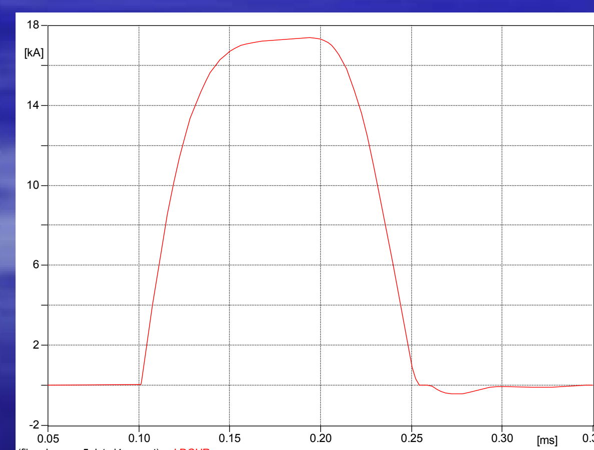


Is Saturating Inductor Needed?

- Without
  - $Idot_{max}$ = 700 A/μs



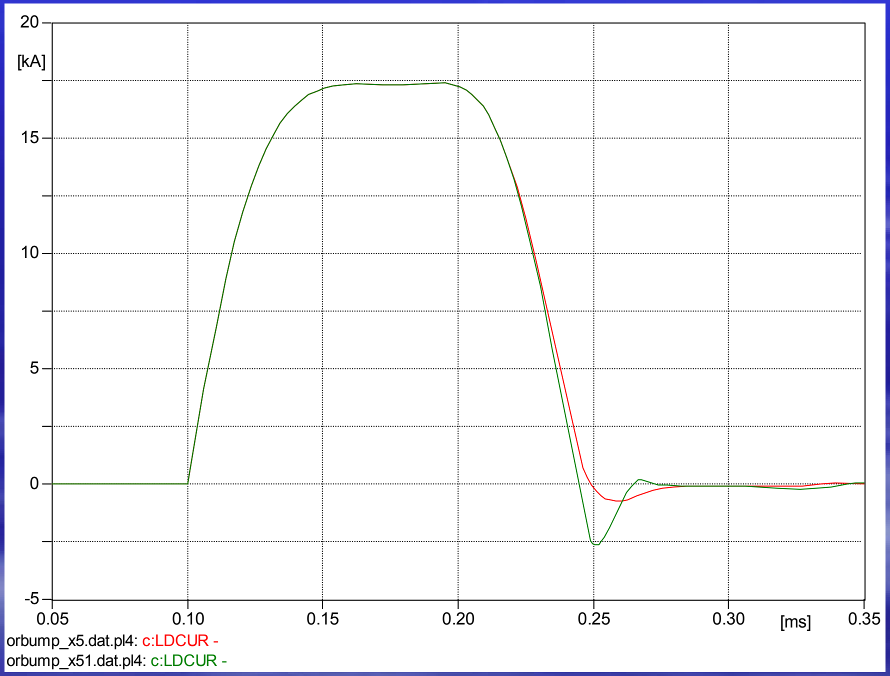
- <u>Not Needed</u>



- With:
  - $Idot_{max}$ = 600 A/μs

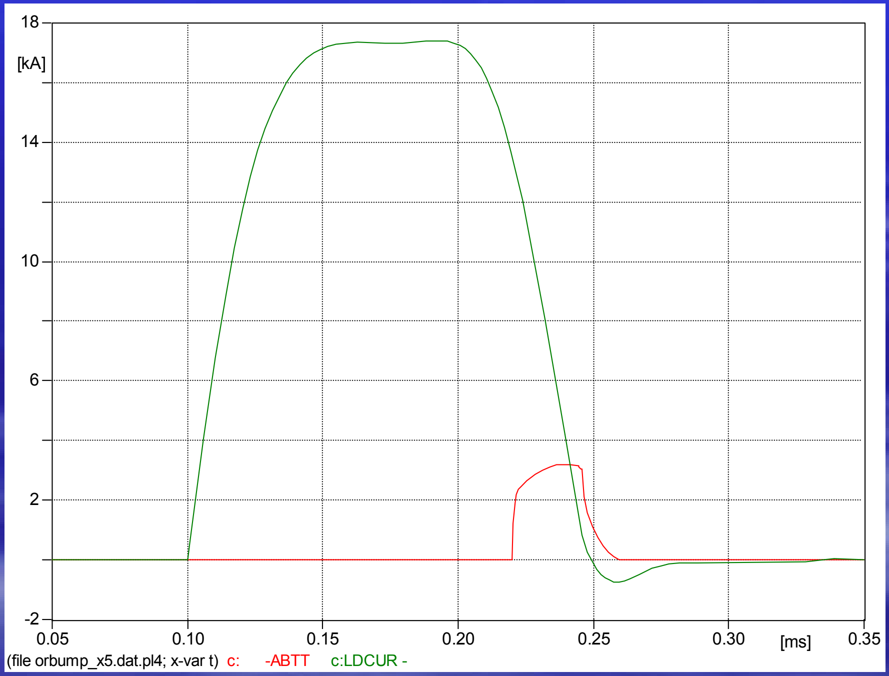
Is End-of-Pulse Clamp Needed?

- 4% vs. 15% undershoot
- <u>Clamp is needed</u>



End-of-Pulse Clamp, cont.

- Switch Parameters:
  - I_{peak} = 3200 A
  - I_{ave} = 2 A
  - I_{rms} = 80 A
  - $T_{conduction}$ = 40μs
  - dI/dt = 600 A/μs
  - V_{peak} = 2050 V
- Design Concerns:
  - Choice of SCR
  - Snubber Design
  - Trigger Design
  - Timing

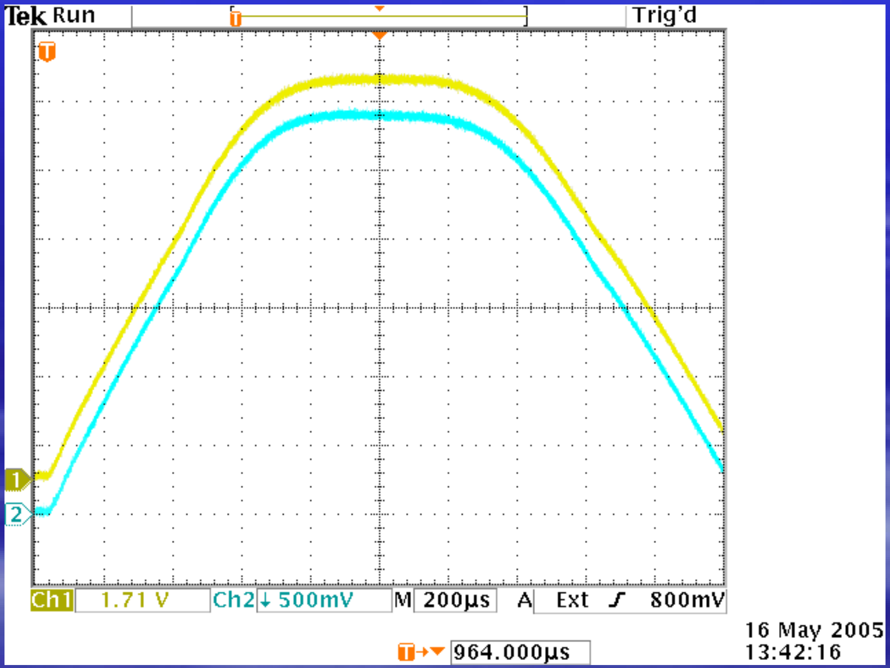


Monitoring - Current

- Pearson Model 1423
- Sensitivity = 0.001 V/A +1/-0%
- 15 V = 15 kA

Monitoring – SCR No Fire

- 5 LEM flex current probes
- Sensitivity 1 mV/A
- 3 kA = 3 V
- Tested at 300 A, 15 Hz



Voltage Monitoring

- Voltage divider Ross VDS-15-DH-K-FS (same as MP01/MP02)
- 300:1
- 1800 V = 6 V (15 kA)

Energy Discharge

- Electronic Crowbar across a PFN capacitor in parallel with Ross relay
- Additional Ross relay across a PFN capacitor
- Ross Relay across charging power supplies (2 sec. delay)
- 200 kΩ bleeder resistors across capacitor (T= 100 sec.)

Safety Hazards

- The charging supplies are 3 kV dc and are powered from 480 V ac.
- Terminals for the capacitor bank (potentially 2.25 kJ, 1 kJ nominal) and high voltage bus (3 kV) are in the cabinet with 4 sets of double doors.

Hazard Mitigation

- All power for the system will come through a 480 V safety switch
- All doors in the power supply cabinet and equipment rack are interlocked to 480 V contactor
- Once 480 V power is removed, safety relays are dropped in; two across the capacitor bank, one (2 second delay) across the charging power supplies to prevent capacitor re-charging
- A resistive ground stick will be provided to accomplish the final grounding of the capacitor bank
- Visual inspection of the discharge resistors on relay assembly

Orbump Controls

Objective:

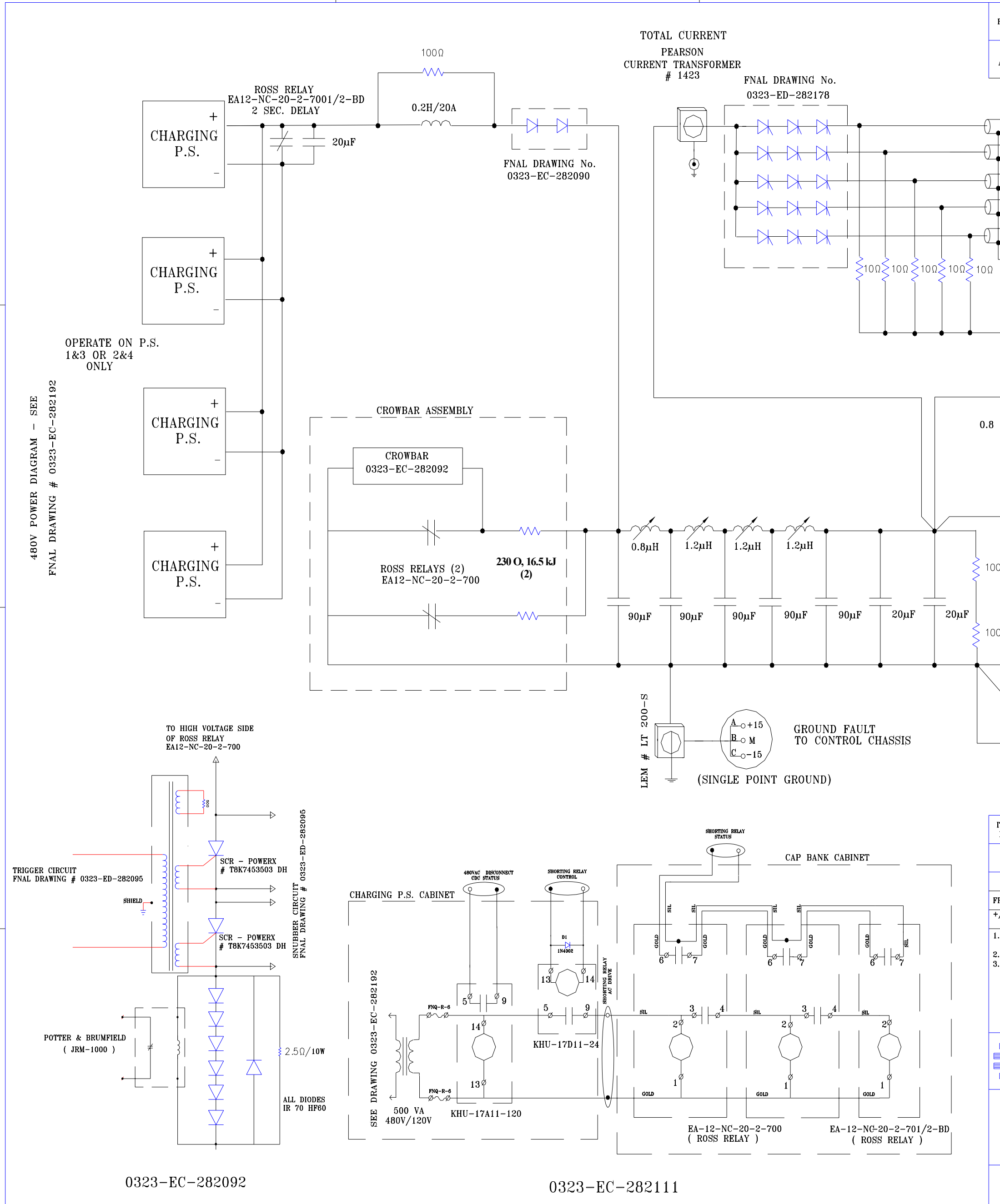
Use as much of MPO1/MPO2 controls as possible.

What can be used from MP01/MP02

- Contact Interface Card.
- Signal Interface Card.
- Timing & Control <u>with timing mods</u>.
- Peak Current Sample & Hold <u>with timing mods</u>.
- Cap Bank Voltage Regulator.
- Analog & Digital Feedback Cards.

What changes need to be made?

- The SCR Switch Current Monitor will need to be redone totally to monitor the 5 SCR Switch signals for a no-fire.
- The Load Current will come from a single CT, not a summation signal.
- The 118 Camac Module will need to be changed to a C217 module.
- A C284 Module will need to be added for more status readbacks.
- Timing Adjustments will need to be made for Peak sample & Hold.
- Minor Chassis wiring for above modifications.
- Charge/Fire Pulses ??
- Chassis Front Panel Display for 5 SCR Switch monitors.



REV.	DESCRIPTION	DRAWN / APPD.	DATE / DATE
A	*	* / *	* / *

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.

PARTS LIST

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	CEZARY JACH	02/15/2005
FRACTIONS +/-	DECIMALS +/-	ANGLES +/-	DRAWN	CEZARY JACH	02/15/2005
			CHECKED		
			APPROVED		

1. BREAK ALL SHARP EDGES 1/64" MAX.
2. DO NOT SCALE DRAWING.
3. DIMENSIONING IN ACCORD WITH ANSI Y14.5 STD'S.

MAX. ALL MACHINED SURFACE

AutoCAD 2000 LT

USED ON

MATERIAL

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

ORBUMP POWER SUPPLY BLOCK DIAGRAM

SCALE	FILMED	DRAWING NUMBER	REV.
NONE		0323-EC-282191	B

Project Cost

- 106k$ spent or committed
- 8k$ estimated additional costs (electronics,, cables, buswork, supports, etc…)
- Does not include Ken's switch
- Does not include installation (electricians, riggers)

Project Labor Estimate (Lab)

- Does not include T&M
- Technicians
  - 13 man-months
- Engineers
  - 6 man-months total

Project Schedule

- All major parts are in-house. Capacitors are due at the end of August, but can be substituted if needed.
- Switch – 100% complete
- Power supply rack – 90% complete
- Controls rack – 50% complete
- Power supply cabinet – 0% complete

Spares

- Capacitors
  - 90 µF – 5 needed, 9 spares
  - 20 µF – 3 needed, 2 spares
- Charging Power Supplies – includes MP01/MP02
  - 10 needed, 3 spares
- Charging Chokes – includes MP01/MP02
  - 3 needed, 2 spares
- Charge Recovery Chokes – includes MP01/MP02
  - 3 needed, 2 spares
- Switch – 5 spare SCR assemblies
- All small parts have spares in various quantities

Documentation

- This document
- Power Supply Checkout (in preparation)
- Power Supply Power On (in preparation)
- Power Supply Scale Factors and Test Points (in preparation)
- Re-commissioning Plan (in preparation)
- LOTO document (in preparation)
- AUTOCAD schematics

Schematics

- ORBUMP Power Supply Block Diagram, FNAL drawing 0232-EC-282191
- ORBUMP 480 V Power Distribution Single Line Diagram, FNAL Drawing 0323-EC-282192
- Most MP01/MP02 schematics will apply
- Modifications and new schematics will be done if necessary